Appendix C

River Phosphorus Concentrations vs. Poultry House Density

The analyses described in this appendix were a collaborative effort of Dr. Roger Olsen, Dr. Tim Cox, and Dr. Bernard Engel. Dr. Cox prepared the text contained in this appendix.

Objectives

The primary objective of this analysis was to investigate for causal links between selected sub-basin characteristics and total phosphorus concentrations in tributaries of the Illinois River. In particular, the impacts of poultry house presence on stream water quality were investigated. A secondary objective was to develop the basis for a simple empirical predictive tool to assist in watershed management.

Methods

This work involved linear regression analyses of data collected as part of the small tributary sampling program in the basin. Data were collected for both highflow and baseflow conditions throughout two summer periods (2005 and 2006). Data were collected from a total of fourteen sampling locations in small tributaries throughout the basin that covered a range of drainage area size and landuse characteristics. In particular, a representative range of poultry house presence (from no presence to highly active presence) was included in the sampling program. Further details of this sampling program are provided in Olsen (2008).

Regression analyses were performed for measured total phosphorus concentrations as a function of a range of hypothesized potential predictor variables, including poultry house densities in local drainage areas. Table 1 summarizes the predictor variables included in the analysis. Predictor variables were generally quantified using a combination of GIS mapping, aerial photographs, and field reconnaissance. Poultry house densities were determined by first identifying and locating potential poultry houses using up-to-date aerial photography of the watershed. These houses were then confirmed through field reconnaissance and categorized as either “active”, “temporarily inactive”, or “abandoned”. The house locations were then mapped in GIS and densities were calculated as the number of houses in the targeted sub-basin divided by the area of the sub-basin (Fisher, 2008). Only active houses were included in the “active house density - AHD” calculations while all houses (active + inactive + abandoned) were included in the “total house density – THD” calculations. Soil Conservation Service Curve Numbers (SCS CN) were estimated by first intersecting GIS layers of soil hydrologic type (A – D) and landuse category. Table 2 of the USDA Technical Release-55 (“Urban Hydrology for Small Watersheds”) was then used to assign curve numbers to each intersection area of each sub-basin. Finally, these values were used to calculate area-weighted average curve numbers for each sub-basin. Other parameters listed in 1 were calculated using standard GIS mapping and calculation methods.

High flow and baseflow data were separated for this analysis. Total phosphorus concentration data were pooled in three ways: 2005 only, 2006 only, and combined 2005 – 2006. For the high flow analysis, flow-composited samples from each event were averaged for each time period pool for each sampling station. In other words, a single average value was generated for each

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pool and each station. The flow-weighted averaging method used here applied weightings to each event based on the relative size of the event. Flow-weighted averages were calculated as:

$$TP_{avg} = \frac{1}{\sum_{n=1}^{numEvents} Vol_i} \sum_{n=1}^{numEvents} EMC_i Vol_i$$

where TP_{avg} = the flow-weighted average phosphorus concentration, i = index for a given sampled storm event, numEvents = number of sampled storm events, Vol_i = total runoff volume for storm event i, and EMC_i = measured event mean phosphorus concentration for event i. In this way, the values assigned to each station better capture the relationships between total mass *loads* and sub-basin characteristics. Thus, a small runoff event that results in high phosphorus concentrations is weighted less in the calculations than a large event which results in lower concentrations to reflect the relative mass loads of the two events.

Straight averaging across sampling events was used for the baseflow data.

Two of the sampling stations, Site HFS 04 and HFS 22, were excluded from the statistical analysis described here due to the presence of point sources within the station sub-basins. Stream water quality at these two sites is dominated by effluent from the City of Siloam Springs wastewater treatment plant and the City of Lincoln wastewater treatment plant, respectively. These sites were sampled to provide information on the mass loads contributed by these types of facilities but are not appropriate for inclusion in the analysis described here. Additionally, 2006 data from HFS 14 were excluded from the analysis. While this site was a verified reference site in 2005 (no poultry activity in the sub-basin), poultry waste spreading was observed on a field immediately upstream of the sampling site in 2006. Therefore, the original landuse designation (forested) and poultry house density (0 houses/mi.) were not valid in 2006 and the data collected during this sampling period were omitted from the analysis.

Microsoft Excel was used to calculate correlation coefficients (R^2 values) and significance levels (p values) for each pairing of predictor variable and total phosphorus concentration. A statistically significant correlation was defined as one in which $p \leq 0.05$ (95% significance level).

Results and Discussion

Table 2 summarizes the results of the regression analysis. Graphical results of two sets of regressed data with high correlation coefficients, high significance, and good data spread are shown in Figures 1 and 2.

As can be seen, sub-basin poultry house densities, in a variety of forms, appear to be strong predictors of stream total phosphorus concentration. This is particularly true when the 2005 and 2006 data are pooled and a more comprehensive data set is formed. For the combined 2005-06 data sets, all 6 of the poultry house density predictor variable forms are shown to be significantly and positively correlated with total phosphorus concentrations in the receiving streams during highflow events. Overall, 21 out the 36 TP vs. poultry density regressions show significant and positive correlations. The strongest and most convincing correlations appear to be for the pooled 2005 – 06 phosphorus concentrations vs. total and active poultry house densities within a 2 mile buffered drainage area (Figures 1 and 2). These results indicate that poultry house density could be used as a predictor of stream phosphorus concentrations in this watershed. Additionally, the relationships established here could be used to guide watershed management decisions.

Septic tank density is also shown to be a statistically significant predictor of stream phosphorus concentration for most of the data combinations. However, these correlations are not generally as strong as those associated with poultry house density, particularly for high flow conditions. Additionally, a strong cross correlation is observed between septic tanks and total poultry house density within the 2 mile buffered area (see Figure 3). In other words, in areas with high poultry house development, human dwellings are also relatively high. This is not unexpected. Finally, an independent analysis of the total phosphorus loading expected from septic tanks in the watershed has shown these contributions to be negligible relative to the total mass loading in the systems (see Appendix G). These factors lead us to conclude that a true causal relationship between septic tanks and stream phosphorus concentration does not exist. Rather, the perceived correlation between these variables is simply an artifact of the cross-correlation between residential dwellings and poultry house presence.

The Soil Conservation Service Curve Number (SCS CN) is shown to be a significant predictor of the 2005 baseflow TP concentrations (positive correlation). Similarly, the percent of the sub-basin stream length with riparian buffers is shown to be a significant predictor of 2006 highflow TP concentrations (negative correlation). Both of these parameters are significantly correlated with only one of the six TP datasets, and neither is significantly correlated with the most comprehensive dataset (pooled 2005-06 data). Therefore, we conclude that these parameters are, at best, weak predictors of stream phosphorus concentration.

Table 1
Potential Total Phosphorus Predictor Variables

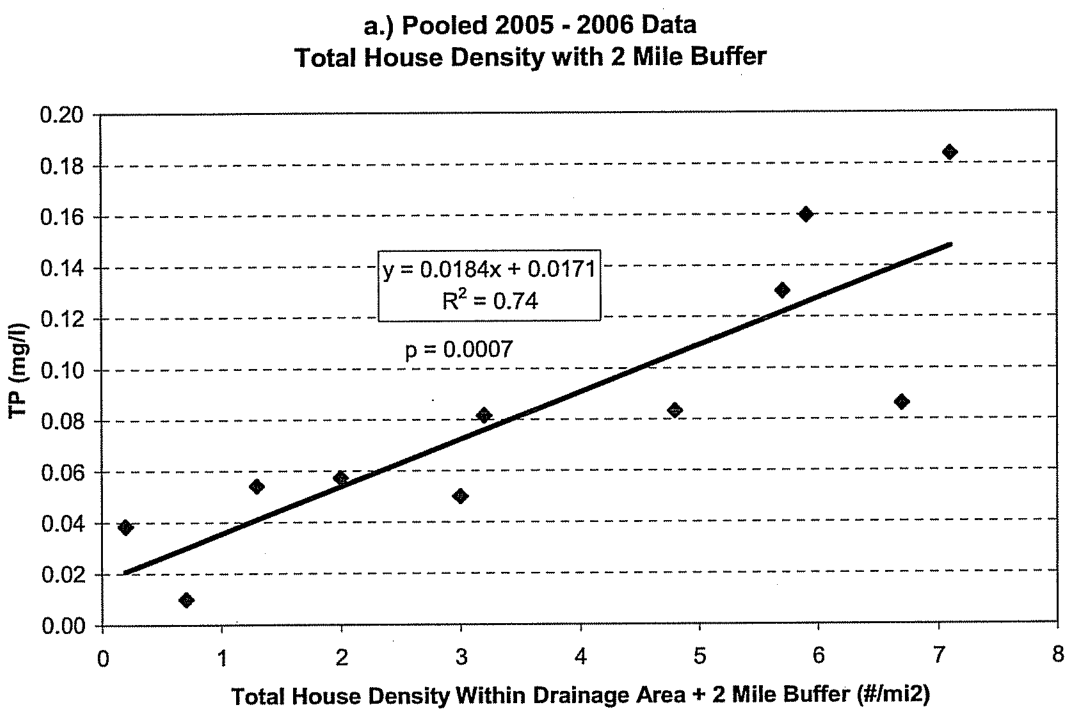
Variable	*Description*	*Rationale*
Total House Density (THD)	density (houses per mi^2) of all identified poultry houses, including inactive houses, in sub-basin	poultry waste is spread on fields in vicinity of poultry houses *(expected positive correlation)*
Active House Density (AHD)	density (houses per mi^2) of all identified active poultry houses in sub-basin	""
THD – 1 mile buffered	density (houses per mi^2) of all identified poultry houses in sub-basin plus 1 mile perimeter buffer	tributary water quality may be impacted by poultry houses a short distance outside of sub-basin (waste transported from a house outside the basin to a field inside the basin) *(expected positive correlation)*
AHD – 1 mile buffered	density (houses per mi^2) of all identified active poultry houses in sub-basin plus 1 mile perimeter buffer	""

THD – 2 mile buffered	density (houses per mi^2) of all identified poultry houses in sub-basin plus 2 mile perimeter buffer	approximately 80% of poultry waste is spread on fields within 2 miles of poultry house (Fisher, 2008) *(expected positive correlation)*
AHD – 2 mile buffered	density (houses per mi^2) of all identified active poultry houses in sub-basin plus 2 mile perimeter buffer	""
SCS CN	Soil Conservation Service Curve Number	sub-basins with varying runoff potential may differ in their impact on receiving stream water quality
Septic Tank Density	estimated density (tanks per mi^2) of septic tanks in sub-basin	leaching from septic tanks may carry a significant phosphorus load *(expected positive correlation)*
% Pasture	percent of pasture in sub-basin	amount of pasture in a sub-basin can serve as a surrogate for agricultural activity which may be a good predictor of stream phosphorus concentration *(expected positive correlation)*
% Riparian Buffer	percent of stream length in sub-basin that is buffered by forest	riparian buffers can filter nutrients from runoff prior to entering streams *(expected negative correlation)*
Median Distance to Chicken Houses	median of distances (mi) from poultry houses in the sub-basin to the sampling site	poultry houses closer to the stream may have a greater impact on water quality than those further away *(expected negative correlation)*

Table 2
Regression Analysis Results Summary[1]

	2005 Highflow	**2005 Baseflow**	**2006 Highflow**	**2006 Baseflow**	**2005 – 06 Highflow**	**2005 – 06 Baseflow**
THD	0.64	0.86	0.14	0.66	0.76	0.68
AHD	0.32	0.73	0.26	0.49	0.56	0.47
THD – 1 mi	0.28	0.63	0.39	0.31	0.65	0.3
AHD – 1 mi	0.13	0.42	0.49	0.18	0.49	0.19
THD – 2 mi	0.48	0.63	0.27	0.35	0.74	0.36
AHD – 2 mi	0.49	0.64	0.28	0.33	0.74	0.36
SCS CN	0.18	0.43	0.14	0.40	0.23	0.27
Septic Tanks	0.48	0.52	0.15	0.57	0.37	0.41
% Pasture	0.13	0.13	0.09	0.01	0.12	0.01
% Rip. Buff.	0.03	0.09	0.49	0.19	0.18	0.12
Med. Dist. CH	0.11	0.07	-0.25	0.01	0.04	0.001

1 = statistically significant correlations ($p \leq 0.05$) indicated by highlighting



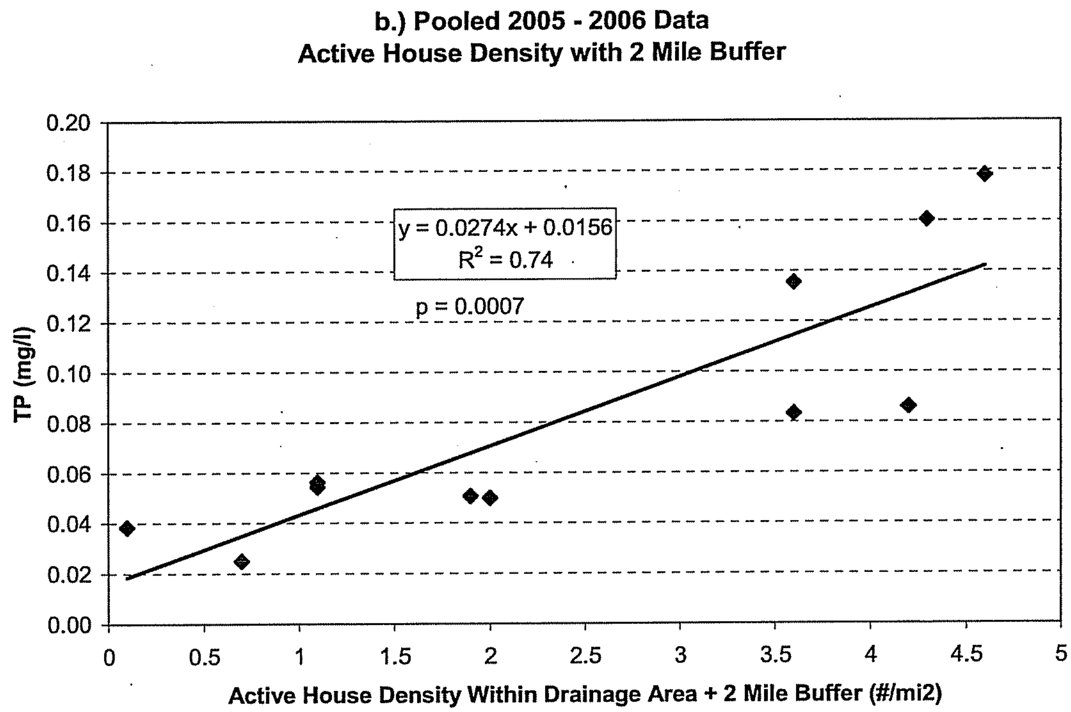
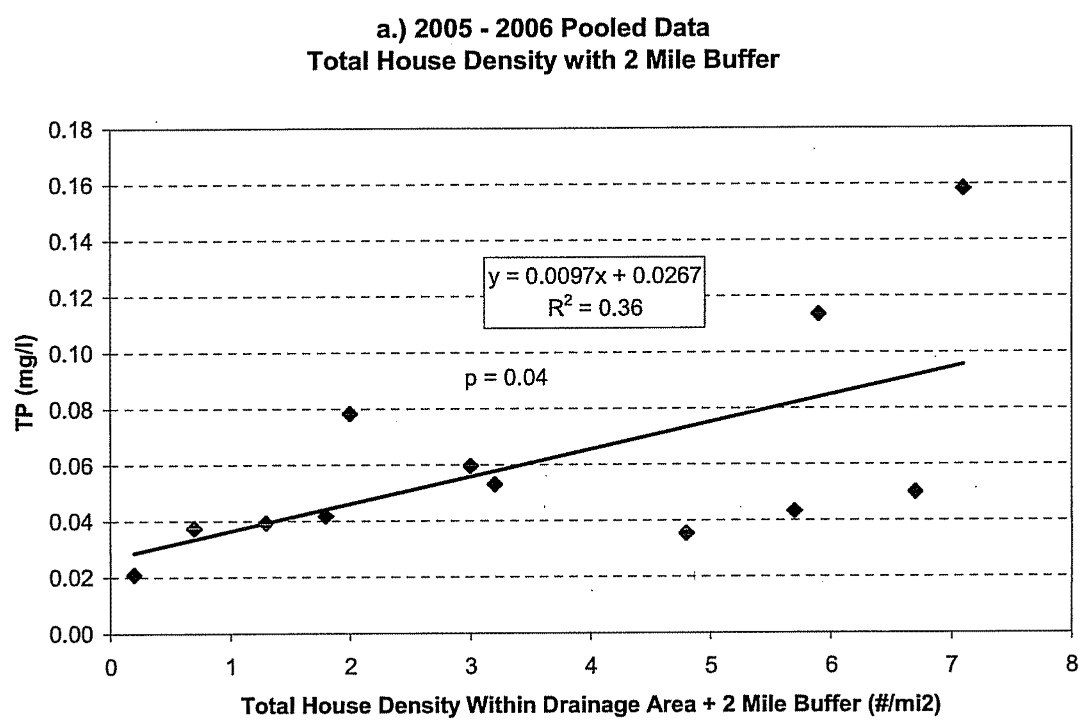


Figure 1. Highflow Regressions: Total Phosphorus Concentration vs. Poultry Presence



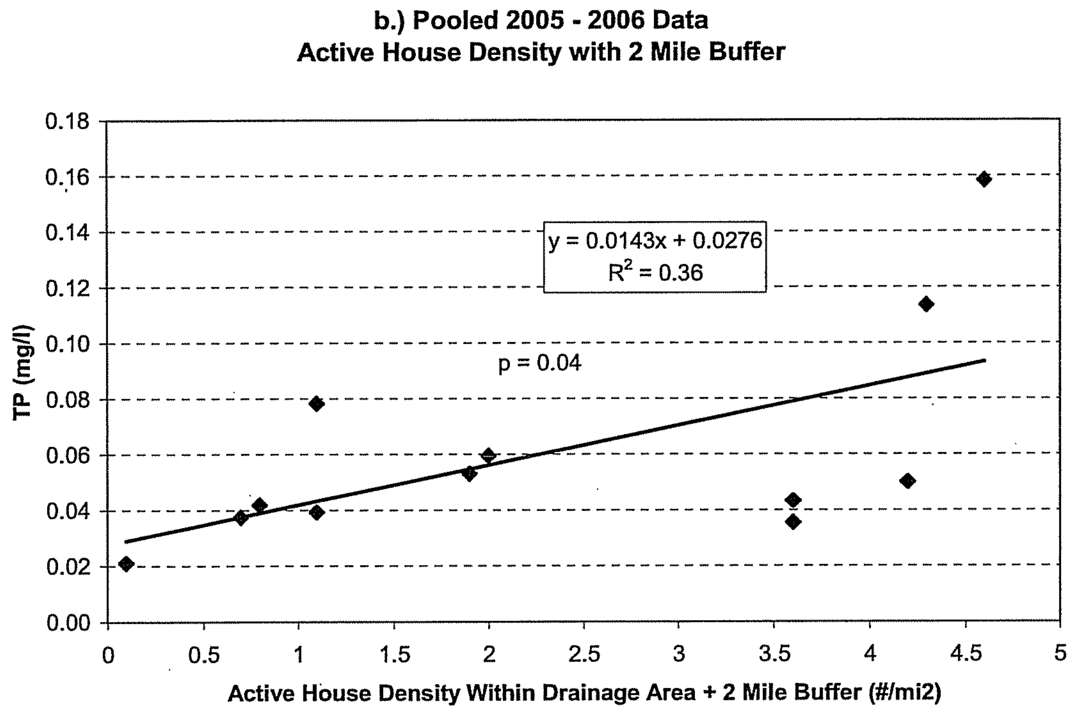


Figure 2. Baseflow Regressions: Total Phosphorus Concentration vs. Poultry Presence

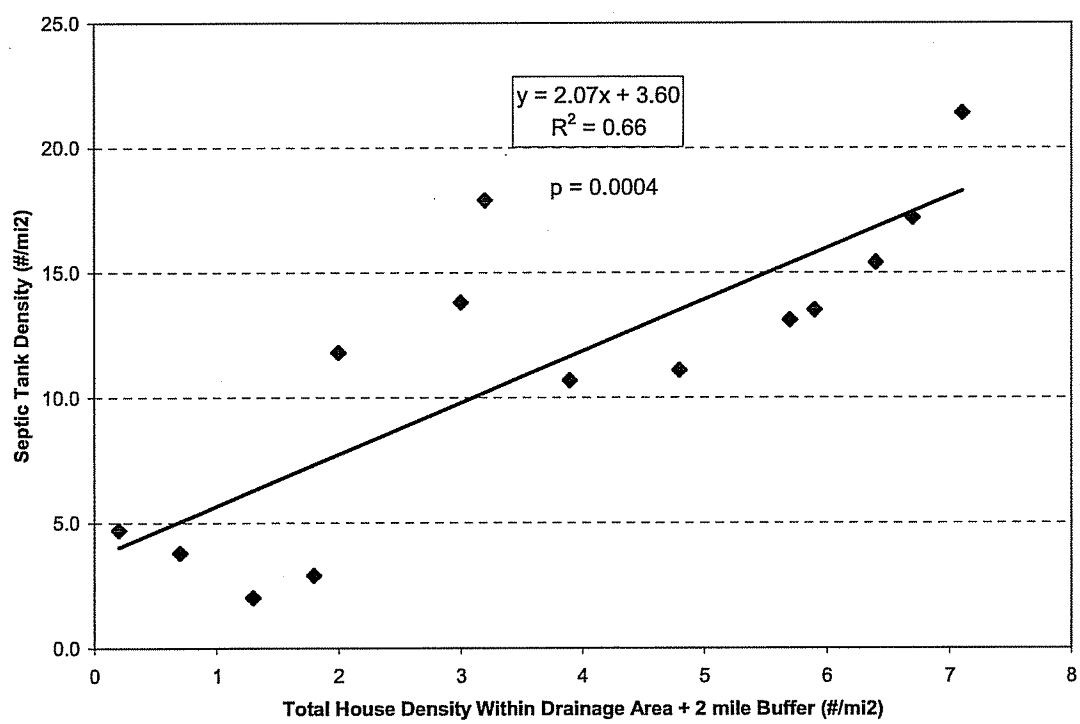


Figure 3 Cross Correlation Between Septic Tank Density and Poultry Presence